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Experimental Investigation on Effect to the Specific Strength of FDM Fabrication Parameters Using Taguchi Method

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Abstract

The Fused Deposition Modeling (FDM) fabrication is commonly used printing technique, the reasons behind this are low consumable cost, simplicity of workflow and more reliable. The quality of the printed parts depends on various process variables such as part orientation, layer thickness, hotend and bed temperature, fabricating speed, infill pattern and infill density, number of top-bottom solid layers, number of shells etc. Literature suggests that infill density, number of shells and number of top-bottom solid layers are variables that changing the tensile strength under tension of 3D fabricated parts and also have effect on weight of the parts. This study focuses on effect of infill density (ID), number of shells (NS) and top-bottom solid layers (TBSL) on specific strength (strength/weight ratio). Taguchi L18 Orthogonal Array (OA) design is used to perform the experiments. 18 runs with 3 repeated specimens were printed according to the ASTM D638 Type I standard using different printing variables. According to the results, parameters increase of ID, NS and TBSL were seen to effect significant improvement in the specific strength increase. However, between 40-60% ID has negative effect to specific strength while NS and TBSL increase.

Keywords: Fused Deposition Modelling, Specific Strength, 3D printing, Taguchi Method

1. INTRODUCTION

3D printing technology is used by defence and aviation, medical, automotive, logistics, food and other related industry due to its physical size, easy definition of workflow and cost effective fabrication of conceptual design, prototypes and functional components [1]. The usage of 3d printed components are increased day by day because of lower assembly and material expense of 3d printers. 3d printers using different production technologies and materials are

commercially available such as Stereolithography (SLA), Fused Deposition Modeling (FDM), Binder Jetting (BJ), Digital Light Processing (DLP). Working conditions, mechanical properties of parts, number of products and product quality etc. are played an important role in the selection of 3d printer. FDM type 3d printers are the most used printer type after resin based printers (SLA) due to their ease of production, low operating cost and different material usage options [2]. In this type of printers, the continuous filament fed from the reel is

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extruded from the heated nozzle and laid according to the layer prepared in the slicing program and this process continues layer by layer until the part is produced. Schematic model of FDM process is shown in Figure 1 [3]. The part fabricated with FDM has 85% of the strength of the part that conventional manufacturing techniques used [4]. However, many variables such as layer height, printing speed, hot end and bed temperature, infill pattern, ID, NS and TBSL etc. should be optimized to produce part that has good mechanical properties. [5].

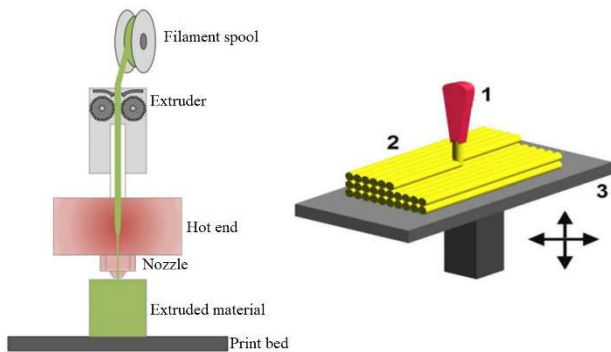


Figure 1 Schematic model of FDM printing (1-nozzle, 2-building material, 3-print bed) [3]

Nowadays, experimental research on FDM technology is still a novel technology and many researchers is investigated the influence of process variables on tensile properties of fabricated parts, for example, Tontowi et al. examined the effects of nozzle temperature, layer thickness and raster angles on tensile properties of build parts using Taguchi method [6]. Alafaghani et al. worked on the effect of some fabrication variables on tensile and geometric properties [7]. Monterol et al. studied the process parameters of FDM, using the design of experiment (DOE) approach [8]. Cristian et al. worked on influence of different infill rates, infill patterns and printing direction on mechanical properties of printed specimens [9]. Gebisa et al. investigated on the flexural strength of FDM fabricated samples that have different process parameters. [10]. Wang et al. studied the influence of various printing variables, including layer thickness, printing temperature and speed on the tensile properties [11]. Alafaghani et al. examined the selected four fabricating variables using Taguchi [12]. Christian et al. inspected the effect of printing

parameters on the tensile and flexural strength of ABS composite parts [13]. Mostafa et al. worked on to find out the maximization model for the strength to cost ratio using Taguchi prediction model [14]. The motivation of this work is to examine influence of ID, NS, TBSL on the specific strength (strength/weight ratio) of fabricated specimens using PLA (Polylactic acid) according to the ASTM 638 Type I standard.

2. METHODOLOGY

2.1. Taguchi Method

Taguchi technique is the most commonly used method to make design optimization efficiently. This method uses orthogonal array to reduce the number of test to a reasonable one, in terms of cost and time. [15]. Taguchi L18 OA was used to investigate the effect of the ID, NS and TBSL. An OA means the design is well balanced so that factor levels are weighted equally. Therefore, each factor can be analyzed independently of all the other factors, so the effect of one factor does not effect the estimation of other factor [16]. The ID has 6 levels, and the NS and TBSL have 3 levels as shown in Table 1.

Table 1

Level values for each variable

Variable	Level Values					
ID (Infill density) %	0	20	40	60	80	100
NS (No. of shells)	1	2	3			
TBSL (Top-bottom solid layer)	2	3	4			

Table 2 show that the value of printing variables with different levels used to fabricate tensile samples for each run. Each run was printed 3 times to control for repeatability of the obtained results and 54 specimens were fabricated for this study. During the fabrication some printing specification were remained constant like layer thickness at 0.2mm, the printing speed at 45.0 mm/s, the infill pattern at rectilinear, the nozzle and bed temperature at 195°C and 60°C, respectively.

Table 2
L-18 Orthogonal array

Run	ID (%)	NS	TBSL	No. of Specimen
1	0	1	2	3
2	0	2	3	3
3	0	3	4	3
4	20	1	2	3
5	20	2	3	3
6	20	3	4	3
7	40	1	3	3
8	40	2	4	3
9	40	3	2	3
10	60	1	4	3
11	60	2	2	3
12	60	3	3	3
13	80	1	3	3
14	80	2	4	3
15	80	3	2	3
16	100	1	4	3
17	100	2	2	3
18	100	3	3	3

2.2. Specimens Preparation

ASTM D638 Type I specimen was chosen due to fabrication time and repeatability. The specimen's shape and dimensions are shown in Figure 2. Solid model of specimen was designed in PTC Creo and converted to STL format with the same software and then the STL file were converted to G-code files with PrusaSlicer software and made ready for fabrication.

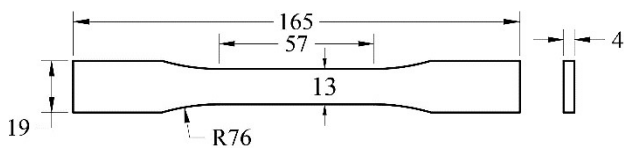


Figure 2 Dimensions of the ASTM D638 Type I tensile specimen, dimensions in mm

All samples were printed using the same spool and fabricated by a custom design Cartesian type FDM printer (Figure 3a) with 0.4 mm nozzle.

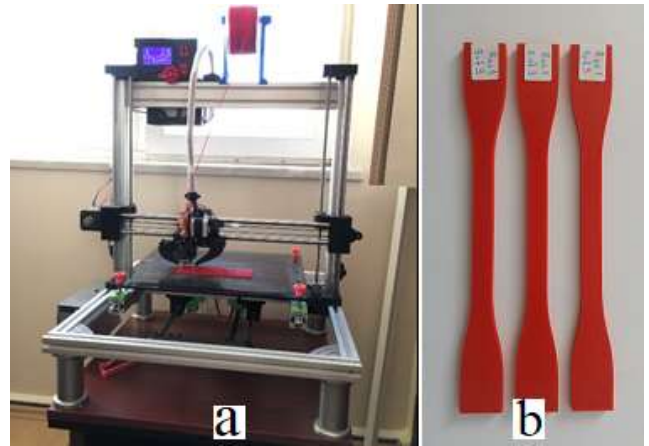


Figure 3 (a) Custom designed printer and (b) fabricated specimens

The filament used in the study has a diameter of 1.75 mm produced by UZARAS under the trade name PLA+. A total of 54 samples were produced and labeled for tensile tests, 3 samples were produced for each run (Figure 3b).

2.3. Weight Measurement and Tensile Testing

Before to examine the tensile properties of the printed specimens, the mass of the samples were measured using precision scales (resolution: 0.001 g) (Figure 4).



Figure 4 Desis NHB+ used in weighing of the specimens

All the samples were tested according to ASTM D638 standards on Zwick testing machine with a capacity of 50 kN (Figure 5). Tensile tests were conducted with a speed of 5 mm/min, following the standard and the test was stopped once the sample broken.



Figure 5 Zwick/Roell Z050 testing machine

Three test specimens were measured and tested for each run (Figure 6) and the evaluations were made by taking the arithmetic average of the weight values, peak load and specific strength values obtained in Table 3.



Figure 6 Tested tensile specimens

Table 3
L-18 Orthogonal array

Run	ID	NS	TBSL	Mean Weight (N)	Mean Peak Load (N)	Mean Specific Strength (N/N)
1	0	1	2	48,667	318	6,5
2	0	2	3	60,175	640	10,6
3	0	3	4	69,494	901	13,0
4	20	1	2	62,084	443	7,1
5	20	2	3	69,125	719	10,4
6	20	3	4	77,486	967	12,5
7	40	1	3	77,149	709	9,2
8	40	2	4	82,881	946	11,4
9	40	3	2	78,205	856	10,9
10	60	1	4	87,924	956	10,9
11	60	2	2	84,513	855	10,1
12	60	3	3	89,480	1086	12,1
13	80	1	3	96,288	1105	11,5
14	80	2	4	98,826	1264	12,8
15	80	3	2	97,269	1245	12,8
16	100	1	4	105,386	1562	14,8
17	100	2	2	105,255	1592	15,1
18	100	3	3	104,650	1609	15,4

3. RESULT AND DISCUSSIONS

The force vs elongation curves of 54 specimen were plotted and shown in Figure 7. The results of tensile test clearly demonstrated that noticeable difference has been found in all the values of test such as max. force and elongation.

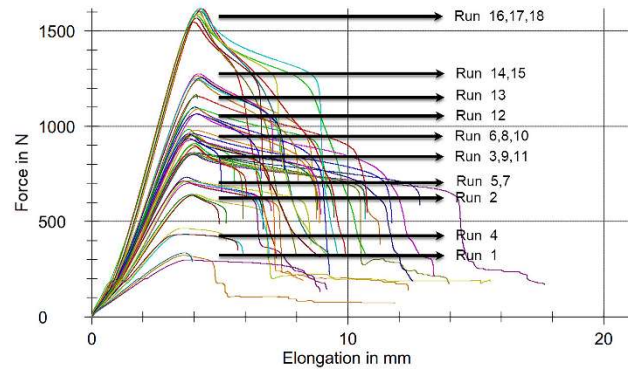


Figure 7 The results of tensile test (load-displacement) for all condition

The maximum peak load (1609 N) has been observed in case of run 18, which was printed at 100% ID, 3 NS and 3 TBSL. This indicates that the highest ID, NS and TBSL reinforce the inner form of specimen which under tensile loading. Using Taguchi design L18 OA analysis, the main effects plots graph Figure 8 were created. The test results were analyzed using the Minitab 19 software.

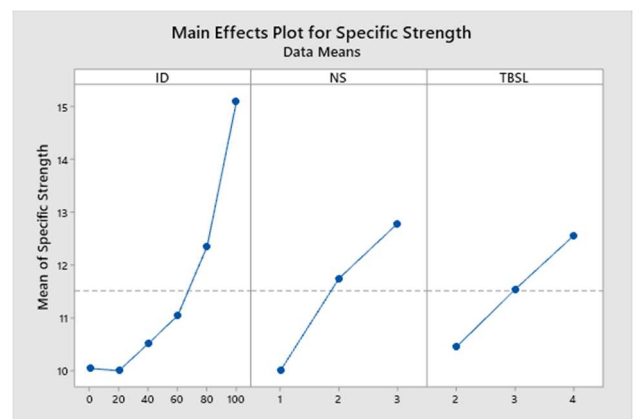


Figure 8 Main effects plot for Specific strength

From the Figure 8 between ID and mean specific strength, it is observed that the sample with 100% ID has the highest specific strength value of 15.4 N/N. Similarly, the specimen with 3 NS and 3 TBSL have the highest specific strength value of

12.78 N/N and 12.55 N/N respectively. However, the specimens with 0-20% ID have approximately the lowest specific strength value of 10 N/N. The lowest values of the NS and TBSL have the lowest specific strength as well (10 N/N and 10.4 N/N respectively). The specific strength increases linearly with increasing NS and TBSL. However, between 0-20% change of the ID does not cause a certain specific strength change. The reason for this is that as the ID increases, the peak load and the weight of the part also increase at a similar rate. Between 20-60% changes of the ID causes to increase specific strength. Furthermore, between 60-100% changes of the ID shows the most significant effect in the specific strength increase. Specific strength changes of test specimen fabricated using different ID, NS and TBSL are given as interaction graphs in Figures 9.

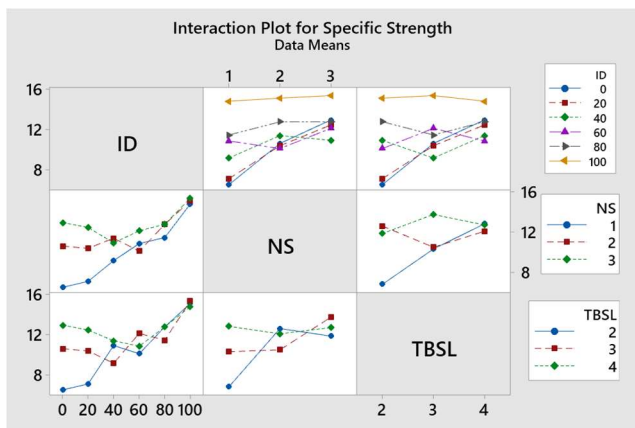


Figure 9 Specific strength changes according to fabrication parameters

When considering the Figure 9, it is seen that ID, NS and TBSL have a positive effect at most scenarios on the specific strength. However, NS and TBSL has no a noticeable effect of specific strength on specimen fabricated with 100% ID. Because of the specific strength was increased due to the high load-carrying capacity per unit area depending on the higher infill density. In addition, while one parameter has the lowest value, increasing the other parameters has a positive effect on specific strength.

4. CONCLUSIONS

In this study, both the effect of parameter levels and their interactions with each other were

investigated using Taguchi method. Taguchi L18 Orthogonal Array was used to examine the influence of ID, NS and TBSL on the specific strength (Peak load/weight) of FDM specimens. 54 samples were tested, because of each of the 18 runs had 3 repeated samples. The results presented that the ID has the most remarkable influence on the specific strength of the FDM specimen as expected. However, between 40-60% ID have negative effect to specific strength while NS and TBSL increase. Considering estimated printing time and the optimal level of fabrication parameters are achieved 40% ID, 2 NS and 3 TBSL, resulting in specific strength of 10.5 N/N, which means 60% of the best result. Overall, it is clear that the set process parameters will have noticeable effect to the tensile properties of 3D fabricated parts. In the future work, the interactions of the specific strength with the fabrication time, part orientation and the other parameters can be investigated.

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No conflict of interest or common interest has been declared by the author.

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